

A simple model of generating fermion mass hierarchy in $N = 1$ supersymmetric $6D$ $SO(10)$ GUT

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Abstract

We suggest simple models which produce the suitable fermion mass hierarchies and flavor mixing angles based on the 6 dimensional $N = 1$ supersymmetric $SO(10)$ grand unified theory compactified on a $T^2/(Z_2 \times Z'_2)$ orbifold. We introduce 6D and 5D matter fields, which contains the 1st and 2nd generation matter fields as the zero modes, respectively. The 3rd generation matter fields are located on a 4D brane. The Yukawa couplings for bulk fields are suppressed by volume factors from extra dimensions. The suitable fermion mass hierarchies and flavor mixings are generated by the volume suppression factors.

1 Introduction

Grand unified theories (GUTs) are very attractive models in which the three gauge groups are unified at a high energy scale. However, one of the most serious problems to construct a model of GUTs is how to realize the mass splitting between the triplet and the doublet Higgs particles in the Higgs sector. This problem is so-called triplet-doublet (TD) splitting problem. A new idea for solving the TD splitting problem has been suggested in higher dimensional GUTs where the extra dimensional coordinates are compactified on orbifolds[1]-[6]. In these scenarios, Higgs and gauge fields are propagating in extra dimensions, and the orbifolding realizes the gauge group reduction and the TD splitting since the doublet (triplet) Higgs fields have (not) Kaluza-Klein zero-modes. A lot of attempts and progresses have been done in the extra dimensional GUTs on orbifolds[7]-[23]. Especially, the reduction of $SO(10)$ gauge symmetry and the TD splitting solution are first considered in 6D models in Refs. [8, 9].

As for producing fermion mass hierarchies, several trials have been done in the extra dimensional GUTs on orbifolds[4, 10, 12, 13, 16, 17, 19, 20, 23]. The model in Ref. [10, 11, 12] can induce the natural fermion mass hierarchies and flavor mixings by introducing extra vector-like generations which propagate 6 and 5 dimensions, respectively. Assuming that 4th (5th) generation vector-like fields only couple to the 1st (2nd) generation chiral fields, the suitable fermion mass hierarchies and flavor mixings are generated by integrating out these vector-like heavy fields. The mixing angles between the chiral fields and extra generations have been determined by the volume suppression factors. The gauge and Higgs fields live in 6 dimensions with the anomaly-free contents, and the orbifolding and boundary conditions make the $SO(10)$ gauge group be broken to $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$ and realize the TD splitting.

In this paper we will suggest an alternative, much simpler scenario based on the 6D $N = 1$ SUSY $SO(10)$ GUT on $T^2/(Z_2 \times Z'_2)$. For matter fields, we do not introduce extra vector-like generations in extra dimensions as in Ref. [10, 11, 12]. We will introduce 6D and 5D vector-like matter fields which contains the 1st and 2nd generation matter fields as the zero modes, respectively. On the other hand, the 3rd generation matter fields are located on a 4D brane. The Yukawa couplings for the 6D and 5D fields are suppressed by volume factors. Then, as the result, the suitable fermion mass hierarchies and flavor mixings are generated at low energy.

2 Fermion mass hierarchies

We consider the 6D $N = 1$ SUSY $SO(10)$ GUT with the vector-like matter contents, whose extra dimensional coordinates are compactified on a $T^2/(Z_2 \times Z'_2)$ orbifold[12]. The structure of extra 2D spaces are characterized by reflection P (Z_2), P' (Z'_2), and translations T_i ($i = 1, 2$). Under the reflection P and P' , (z, \bar{z}) is transformed into

$(-z, \bar{z})$ and $(z, -\bar{z})$, respectively, where $z \equiv (x_5 + ix_6)/2$ and $\bar{z} \equiv (x_5 - ix_6)/2$ with the physical space of $0 \leq x_5, x_6 < \pi R$. Under the translation T_1 and T_2 , (z, \bar{z}) are transformed into $(z + 2\pi R_z, \bar{z})$ and $(z, \bar{z} + 2\pi R_{\bar{z}})$, respectively, where $R_z \equiv (1+i)R/2$ and $R_{\bar{z}} \equiv (1-i)R/2$. The physical space can be taken as $0 \leq z < \pi R_z$ and $0 \leq \bar{z} \leq \pi R_{\bar{z}}$. Thus, the $T_2/(Z_2 \times Z'_2)$ orbifold is just the same as the $S_1/Z_2 \otimes S_1/Z'_2$ orbifold of a regular square. There are four fixed points at $(0, 0)$, $(\pi R_z, 0)$, $(0, \pi R_{\bar{z}})$ and $(\pi R_z, \pi R_{\bar{z}})$, and two fixed lines on $z = 0$ and $\bar{z} = 0$ on the orbifold. The bulk fields are decomposed by P , P' , and T_i . For examples, a 6D bulk scalar field $\Phi(x^\mu, z, \bar{z})$ is decomposed into

$$\Phi_{(\pm\pm)(\pm\pm)}(x^\mu, z, \bar{z}) \equiv \frac{1}{\pi R_c} \phi_{(\pm\pm)_z(\pm\pm)_{\bar{z}}}(x^\mu) \varphi_{(\pm\pm)_z}(z) \varphi_{(\pm\pm)_{\bar{z}}}(\bar{z}), \quad (1)$$

according to the eigenvalues of $(P, T_1)(P', T_2)$ ($= (P, T_1)_z \otimes (P', T_2)_{\bar{z}}$), where $R_c \equiv |R_z| (= |R_{\bar{z}}|)$. Notice that only $\Phi_{(+\pm)(+\pm)}$ can have massless zero-modes and survives in the low energy.

We consider the gauge multiplet and two **10** representation Higgs multiplets propagate in the 6D bulk, which are denoted as \mathbf{H}_{10} and \mathbf{H}'_{10} . We adopted the translations as $T_{51} = \sigma_2 \otimes I_5$ and $T_{5'1'} = \sigma_2 \otimes \text{diag.}(1, 1, 1, -1, -1)$, which commute with the generators of the Georgi-Glashow $SU(5) \times U(1)_X$ [24] and the flipped $SU(5)' \times U(1)'_X$ [25] groups, respectively [8, 9]. Then, translations (T_i) make the $SO(10)$ gauge group be broken to $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$ and realize the TD splitting since the doublet (triplet) Higgs fields have (not) Kaluza-Klein zero-modes.

The zero mode of the 6D bulk matter field, $\psi_{16(+\pm)(+\pm)}$, is classified into four types as

$$\begin{aligned} \psi_{16(++)}(++) & \quad (\text{zero mode}) = Q, \\ \psi_{16(++)}(+-) & \quad (\text{zero modes}) = \overline{U}, \overline{E}, \\ \psi_{16(+-)}(++) & \quad (\text{zero modes}) = \overline{D}, \overline{N}, \\ \psi_{16(+-)}(+-) & \quad (\text{zero mode}) = L. \end{aligned} \quad (2)$$

Similarly, the zero mode of the 5D bulk field, which is propagating on the fixed line $\bar{z} = 0$, is classified into

$$\begin{aligned} \psi_{16(++)} & \quad (\text{zero mode}) = Q, \overline{U}, \overline{E}, \\ \psi_{16(+-)} & \quad (\text{zero mode}) = L, \overline{D}, \overline{N}, \end{aligned} \quad (3)$$

where the 2nd \pm sign represents the T_1 parity.

Now let us discuss matter contents in our model. In Fig.1 we show the the matter configuration on the orbifold. We introduce the 3rd generation matter fields, $\mathbf{16}_3$ of $SO(10)$, on the 4D brane, $(\pi R_z, 0)$. We also introduce vector-like matter fields, $\mathbf{5}_{(-3)_i} + \overline{\mathbf{5}}_{(3)_i}$ and $\mathbf{1}_{(-5)_i} + \overline{\mathbf{1}}_{(5)_i}$ under $SU(5) \times U(1)_X$, on $(\pi R_z, 0)$, where $i = 1, 2$ represents generation index. It is possible to put $SU(5)$ multiplets on the 4D

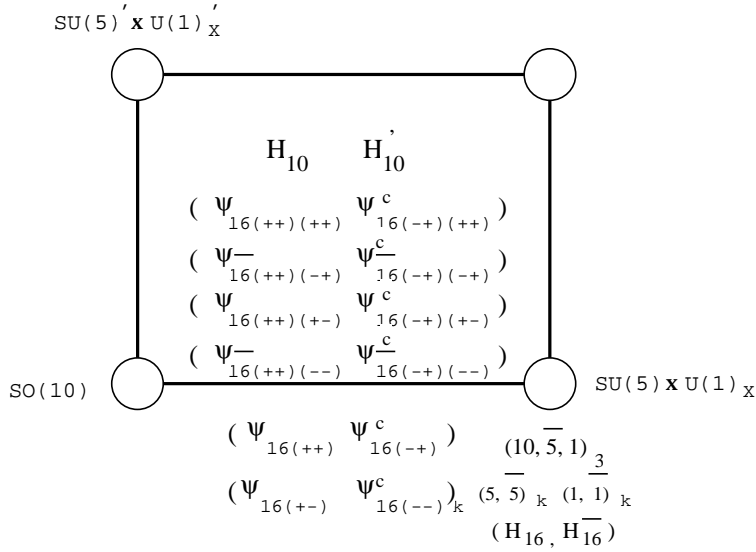


Figure 1: Matter configuration on the orbifold.

brane, $(\pi R_z, 0)$, since the gauge symmetry is the Gero-Glashow $SU(5) \times U(1)_X$ at this 4D brane. On $\bar{z} = 0$, we introduce 5D bulk fields*, $(\psi_{\mathbf{16}(++)}, \psi_{\mathbf{16}^c(-+)})$, which contains $\mathbf{10}_{(-1)}$ of $SU(5) \times U(1)_X$ as the zero mode, and it is regarded as the 2nd generation field. We also introduce two 5D bulk fields, $(\psi_{\mathbf{16}(+-)}, \psi_{\mathbf{16}^c(--)})$ and $(\psi_{\mathbf{16}'(+-)}, \psi_{\mathbf{16}'^c(--)})$, which contain zero mode components $\bar{\mathbf{5}}_{(-3)}$ and $\mathbf{1}_{(-5)}$ of $SU(5) \times U(1)_X$, and they are denoted as $\bar{\mathbf{5}}_{\psi_{\mathbf{16}_i}}$ and $\mathbf{1}_{\psi_{\mathbf{16}_i}}$, respectively. In 6D bulk, we introduce 6D bulk vector-like fields, $(\psi_{\mathbf{16}(++)((++)}, \psi_{\mathbf{16}^c(-+)((++)}) + (\psi_{\mathbf{16}(++)((-+)}, \psi_{\mathbf{16}^c(-+)((-+)})$ and $(\psi_{\mathbf{16}(++)((-+)}, \psi_{\mathbf{16}^c(-+)((-+)}) + (\psi_{\mathbf{16}(++)((-+)}, \psi_{\mathbf{16}^c(-+)((-+)})$, which contain the 1st generation $\mathbf{10}_{(-1)}$ of $SU(5) \times U(1)_X$ as the zero mode. Notice that this matter content induces the gauge anomaly neither on the 4D brane nor in 5D and 6D bulks. We also introduce the 4D brane-localized Higgs fields, $H_{\mathbf{16}}$ and $H_{\mathbf{16}}$, at $(\pi R_z, 0)$, which are assumed to take vacuum expectation values (VEVs) of $O(10^{16})$ GeV in the directions of $B - L$. We impose the Peccei-Quinn symmetry and its charge on the multiplets: The matter fields, $\mathbf{5}_{(-3)_i}$, $\bar{\mathbf{1}}_{(5)_i}$, $\bar{\mathbf{5}}_{\psi_{\mathbf{16}_i}}$, and $\mathbf{1}_{\psi_{\mathbf{16}_i}}$ have zero, other matter multiplets have 1, $\mathbf{10}$ representation Higgs multiplets have -2 , and $\mathbf{16}$ and $\mathbf{16}$ representation Higgs multiplets have -1 .

The superpotential of the brane-localized matter fields is given by[†]

$$W_Y = \frac{1}{M_*} \left(y_{33}^u \mathbf{10}_3 \mathbf{10}_3 \mathbf{5}_{\mathbf{H}_{10}} + \sum_{i=1}^3 y_{3i}^u \bar{\mathbf{5}}_3 \mathbf{1}_i \mathbf{5}_{\mathbf{H}_{10}} + \sum_{i=1}^3 y_{3i}^d \mathbf{10}_3 \bar{\mathbf{5}}_i \bar{\mathbf{5}}_{\mathbf{H}'_{10}} \right) \delta(z - \pi R_z) \delta(\bar{z}), \quad (4)$$

*The 5D bulk fields in $N = 1$ SUSY correspond to super-multiplets in 4D $N = 2$ SUSY.

[†]Notice that the mass terms of vector-like matter fields are forbidden by the PQ symmetry.

in which M_* is an ultraviolet cut-off scale of $O(10^{18})$ GeV. In addition to the superpotential in Eq.(4), there are the following interactions between the brane-localized fields and the bulk fields on the 4D brane, $(\pi R_z, 0)$,

$$\begin{aligned}
W'_Y = & \left\{ \frac{y_{11}^u}{M_*^3} \mathbf{10}_{\psi_{16_1}} \mathbf{10}_{\psi_{16_1}} \mathbf{5}_{\mathbf{H}_{10}} + \frac{y_{22}^u}{M_*^2} \mathbf{10}_{\psi_{16_2}} \mathbf{10}_{\psi_{16_2}} \mathbf{5}_{\mathbf{H}_{10}} \right. \\
& + \frac{y_{12}^u}{M_*^{5/2}} \mathbf{10}_{\psi_{16_1}} \mathbf{10}_{\psi_{16_2}} \mathbf{5}_{\mathbf{H}_{10}} + \frac{y_{13}^u}{M_*^2} \mathbf{10}_{\psi_{16_1}} \mathbf{10}_3 \mathbf{5}_{\mathbf{H}_{10}} + \frac{y_{23}^u}{M_*^{3/2}} \mathbf{10}_{\psi_{16_2}} \mathbf{10}_3 \mathbf{5}_{\mathbf{H}_{10}} \\
& \left. + \sum_{i=1}^3 \frac{y_{1i}^d}{M_*^2} \mathbf{10}_{\psi_{16_1}} \bar{\mathbf{5}}_i \bar{\mathbf{5}}_{\mathbf{H}'_{10}} + \sum_{i=1}^3 \frac{y_{2i}^d}{M_*^{3/2}} \mathbf{10}_{\psi_{16_2}} \bar{\mathbf{5}}_i \bar{\mathbf{5}}_{\mathbf{H}'_{10}} \right\} \delta(z - \pi R_z) \delta(\bar{z}). \quad (5)
\end{aligned}$$

We identify the zero modes of $\mathbf{10}_{\psi_{16_1}}$ and $\mathbf{10}_{\psi_{16_2}}$ as the 1st and 2nd $\mathbf{10}$ massless matter fields, $\mathbf{10}_1$ and $\mathbf{10}_2$, respectively. Below the compactification scale, the interactions in Eq.(5) induce the following Yukawa couplings for the zero modes.

$$\begin{aligned}
W'_Y = & \frac{1}{M_*} \left\{ y_{11}^u \epsilon_1^4 \mathbf{10}_1 \mathbf{10}_1 \mathbf{5}_{\mathbf{H}_{10}} + y_{22}^u \epsilon_2^2 \mathbf{10}_2 \mathbf{10}_2 \mathbf{5}_{\mathbf{H}_{10}} \right. \\
& + y_{12}^u \epsilon_1 \epsilon_2 \mathbf{10}_1 \mathbf{10}_2 \mathbf{5}_{\mathbf{H}_{10}} + y_{13}^u \epsilon_1 \mathbf{10}_1 \mathbf{10}_3 \mathbf{5}_{\mathbf{H}_{10}} + y_{23}^u \epsilon_2 \mathbf{10}_2 \mathbf{10}_3 \mathbf{5}_{\mathbf{H}_{10}} \\
& \left. + \sum_{i=1}^3 y_{1i}^d \epsilon_1 \mathbf{10}_1 \bar{\mathbf{5}}_i \bar{\mathbf{5}}_{\mathbf{H}'_{10}} + \sum_{i=1}^3 y_{2i}^d \epsilon_2 \mathbf{10}_2 \bar{\mathbf{5}}_i \bar{\mathbf{5}}_{\mathbf{H}'_{10}} \right\}. \quad (6)
\end{aligned}$$

The 1st and 2nd generation $\mathbf{10}$ multiplets of $SU(5)$ give the volume suppression factor ϵ_1 and ϵ_2 , respectively, which are given by

$$\epsilon_1 = \epsilon_2 \equiv 1/\sqrt{\pi R_c M_*}. \quad (7)$$

These volume suppression factors play crucial roles for generating the fermion mass matrices in the low energy. Now we set $1/R_c = O(10^{16})$ GeV, which means $\epsilon_i \simeq \lambda^2 \sim 0.04$, where λ is the Cabibbo angle, $\lambda \sim 0.2$. Although the bulk Higgs fields $\mathbf{5}_{\mathbf{H}_{10}}$ and $\bar{\mathbf{5}}_{\mathbf{H}'_{10}}$ also induce the volume suppression factor, ϵ_1 , this effect is not available in the low energy by assuming the original Yukawa couplings y_{us} , y_{ds} being of $O(\epsilon_1^{-1})$ in Eqs.(4) and (6)[†].

For other unwanted matter multiplets, $\mathbf{5}_{(-3)_i}$, $\bar{\mathbf{1}}_{(5)_i}$, $\bar{\mathbf{5}}_{\psi_{16_i}}$, and $\mathbf{1}_{\psi_{16_i}}$, the zero modes become heavy through the mass terms

$$W_v = \sum_{i=1}^2 \frac{1}{M_*^{3/2}} \left(M_5^i \mathbf{5}_i \bar{\mathbf{5}}_{\psi_{16_i}} + M_1^i \bar{\mathbf{1}}_i \mathbf{1}_{\psi_{16_i}} \right) \delta(z - \pi R_z) \delta(\bar{z}), \quad (8)$$

on $(\pi R_z, 0)$, where we set the diagonal bases of M_5^i and M_1^i , for simplicity. It suggests that these unwanted matter fields decouple in the low energy. Therefore the particle

[†]When we input Higgs fields, $\mathbf{5}_{\mathbf{H}_{(2)}}$ and $\bar{\mathbf{5}}_{\mathbf{H}'_{(-2)}}$, on the 4D brane, $(\pi R_z, 0)$, there are no volume suppressions for the Higgs fields, where the original Yukawa couplings y_{us} , y_{ds} are of $O(1)$ in Eqs.(4) and (6). In this case, however, TD splitting should be solved by other mechanisms.

contents at the low energy become the same as those of the minimal SUSY standard model (MSSM) with right-handed neutrinos.

Now let us show the mass matrices of the quarks and leptons. From Eqs.(4) and (6), the mass matrices of the ordinal matter fields are given by

$$m_u^l \simeq \begin{pmatrix} \lambda^8 & \lambda^6 & \lambda^4 \\ \lambda^6 & \lambda^4 & \lambda^2 \\ \lambda^4 & \lambda^2 & 1 \end{pmatrix} v, \quad m_d^l \simeq \begin{pmatrix} \lambda^4 & \lambda^4 & \lambda^4 \\ \lambda^2 & \lambda^2 & \lambda^2 \\ 1 & 1 & 1 \end{pmatrix} \bar{v}, \quad m_e^l \simeq \begin{pmatrix} \lambda^4 & \lambda^2 & 1 \\ \lambda^4 & \lambda^2 & 1 \\ \lambda^4 & \lambda^2 & 1 \end{pmatrix} \bar{v}, \quad (9)$$

for the up quark sector, the down quark sector, and the charged lepton sector, respectively [10]. \bar{v} and v are the vacuum expectation values of the weak Higgs doublets. We write the mass matrices in the basis that the left-handed fermions are to the left and the right-handed fermions are to the right. We notice that all elements in the mass matrices have $O(1)$ coefficients. The fermion mass hierarchies are given by

$$m_t : m_c : m_u \simeq 1 : \lambda^4 : \lambda^8, \quad (10)$$

$$m_b : m_s : m_d \simeq m_\tau : m_\mu : m_e \simeq 1 : \lambda^2 : \lambda^4, \quad (11)$$

with the large $\tan\beta$. The mass matrix of three light neutrinos $m_\nu^{(l)}$ through the see-saw mechanism[26] is given by

$$m_\nu^{(l)} \simeq \frac{m_\nu^D m_\nu^{DT}}{M_R} \simeq \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \frac{v^2}{M_R}. \quad (12)$$

M_R is about 10^{14} GeV induced from the interaction

$$W_{MN} = \frac{y_{ij}^N}{M_*} \bar{\mathbf{I}}_{H_{16}} \bar{\mathbf{I}}_{H_{16}} \mathbf{1}_i \mathbf{1}_j \delta(z - \pi R_z) \delta(\bar{z}) \quad (13)$$

on $(\pi R_z, 0)$. We can obtain the suitable mass scale ($O(10^{-1})$ eV) for the atmospheric neutrino oscillation experiments, by taking account of the $SO(10)$ relation, $y_u \simeq y_\nu$.

As for the flavor mixings, the CKM[27] and the MNS[28] matrices are given by

$$V_{CKM} \simeq \begin{pmatrix} 1 & \lambda^2 & \lambda^4 \\ \lambda^2 & 1 & \lambda^2 \\ \lambda^4 & \lambda^2 & 1 \end{pmatrix}, \quad V_{MNS} \simeq \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}. \quad (14)$$

which realize the suitable flavor mixings roughly in order of magnitudes. They give us a natural explanation why the flavor mixing in the quark sector is small while the flavor mixing in the lepton sector is large[29]-[30]. For the suitable values of V_{us} , U_{e3} , and down quark and electron masses, we need suitable choice of $O(1)$ coefficients in mass matrices as in Ref. [29]. Or, if $O(1)$ coefficients are not determined by a specific reason (symmetry) in the fundamental theory, it is meaningful

to see the most probable hierarchies and mixing angles by considering random $O(1)$ coefficients[30]. Anyway, if the fermion mass hierarchies and flavor mixing angles should be determined from the fundamental theory in *order* (power of λ) not by tunings of $O(1)$ coefficients, we should modify our mechanism. The modification in our scenario can be achieved in a simple way. We introduce a $(\psi_{\mathbf{16}_{(+-)}}, \psi_{\mathbf{16}_{(-)}}^c)$ matter hyper-multiplet with PQ-charge 1 on $\bar{z} = 0$, instead of the brane-localized $\bar{\mathbf{5}}_1$. By identifying the zero mode of this matter field as the 1st generation $\mathbf{5}$ of $SU(5)$, the 1st generation $\mathbf{5}$ induces a volume suppression factor, λ^2 , similar to the case of $\mathbf{10}_{1,2}$ representations. By this modification, we can obtain the modified mass matrices of quarks and leptons, which can induce the suitable values of V_{us} , U_{e3} , and down quark and electron masses (this type of mass matrices is the modification I in Ref. [11]). Furthermore, when we introduce $(\psi_{\mathbf{16}_{(+-)(++)}}, \psi_{\mathbf{16}_{(-)(++)}}^c) + (\psi_{\mathbf{16}_{(+-)(-+)}}^c, \psi_{\mathbf{16}_{(-)(-+)}}^c)$ and $(\psi_{\mathbf{16}_{(+-)(+-)}}, \psi_{\mathbf{16}_{(-)(+-)}}^c) + (\psi_{\mathbf{16}_{(+-)(--)}}^c, \psi_{\mathbf{16}_{(-)(--)}}^c)$, in 6D bulk, and two $(\psi_{\mathbf{16}_{(+-)}}, \psi_{\mathbf{16}_{(-)}}^c)$ s on $\bar{z} = 0$ (these bulk fields contain $\mathbf{5}$ matter fields of $SU(5)$ as the zero modes), and identify the zero modes $\mathbf{5}$ fields as 1st and 2nd, 3rd generations, respectively, we can obtain mass matrices of the small $\tan\beta$ case in the similar manner (modification II in Ref. [11]).

3 Summary and Discussion

In this paper, we have shown the models based on the 6D $N = 1$ SUSY $SO(10)$ GUT where the 5th and 6th dimensional coordinates are compactified on a $T^2/(Z_2 \times Z'_2)$ orbifold. The gauge and Higgs fields live in 6 dimensions. The TD splitting and the gauge symmetry reduction are realized by the orbifolding. The matter fields are contained with the anomaly-free contents. We introduce the 6D and 5D matter fields, which contains the 1st and 2nd generation fields as the zero modes, respectively. The Yukawa couplings for the bulk fields are suppressed by the volume factors. The fermion mass hierarchy has been realized, since the 1st (2nd) generation fields propagate in 6D (5D). We have shown that the suitable fermion mass hierarchies and flavor mixings are generated by the volume suppression factors originated from extra dimensions.

Let us briefly discuss the SUSY breaking mechanisms. In the gaugino mediation scenario [31], the SUSY breaking field, $S = \theta^2 F$, are located at a different fixed point from our brane, $(\pi R_z, 0)$. Then the gauginos obtain the SUSY breaking masses from the interaction with $S = \theta^2 F$. The SUSY breaking for brane-localize matter fields are generated through the quantum effects of the gaugino masses. While the matter fields in extra dimensions can directly couple to the SUSY breaking fields, where non-universal contributions to SUSY breaking masses can be generated in general. Since these non-universal SUSY breaking masses can give rise to too large flavor changing neutral currents (FCNCs), the location of the SUSY breaking brane should be determined in order to avoid the large FCNC phenomenological problems in the gaugino mediation scenario[12]. On the other hand, in the gauge mediation

scenario, we can put the messenger sector on the 4D brane, $(\pi R_z, 0)$, as in Ref. [12]. The SUSY breaking masses for the light matter fields are highly degenerated where the FCNCs are naturally suppressed as in the ordinal 4D gauge mediation models. For other SUSY breaking scenarios, the non-universal corrections to the soft SUSY masses can be arisen in the gravity mediation scenario in general. It is because the SUSY breaking effects are mediated by “Yukawa” interactions not by gauge interactions. The “Yukawa” interactions among the bulk fields always receive the volume suppressions, which violate the degeneracy of the soft SUSY breaking masses. The Scherk-Schwarz SUSY breaking [32, 33] might also give the non-negligible effects of breaking degeneracy, since the first and the second generation fields are mainly composed by the bulk fields in our models.

Acknowledgment

We would like to thank A. Sugamoto for helpful discussions. This work is supported in part by the Grant-in-Aid for Science Research, Ministry of Education, Culture, Sports, Science and Technology, of Japan (No. 14039207, No. 14046208, No. 14740164).

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